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Sustainable energy options for Pakistan

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ABSTRACT

With the advent of the year 2008, Pakistan faces a gap of 4500 MW between the demand and supply of electricity, registering a shortfall of 40%. The article provides an overview of the key dimensions of the crisis, i.e. growing gap between demand and supply, diminishing indigenous oil and gas reserves, rising energy cost and security concerns. It also explores hydropower, solar energy, biomass and wind power as sustainable energy options for the country. In has been found that the total estimated hydropower potential is more than 42 GW out of which only 6.5 GW has been tapped so far. In terms of available solar energy Pakistan is amongst the richest countries in the world, having an annual global irradiance value of 1900–2200 kWh/m^2. Despite that fact that the biomass plays an important role in the primary energy mix by contributing to 36% of the total supplies, it has not managed to break into the commercial energy market. Wind power, also been identified as a potential source of energy, is yet to take off.

Contents

1. Introduction

Provision of sufficient, secure and affordable energy is indispensable to continued human development. Throughout the course of history, with the evolution of civilizations, the human demand for energy has continuously risen. The global demand for energy is rapidly increasing with increasing human population, urbanization and modernization. The world heavily relies on fossil fuels to meet its energy requirements—fossil fuels such as oil, gas and coal are providing almost 80% of the global energy demands. On the other hand presently renewable energy and nuclear power are, respectively, only contributing 13.1% and 6.5% of the total energy needs [1]. The growth in global energy demand is projected to rise sharply over the coming years. The global daily consumption of oil presently stands at 85 million barrels. According to conservative estimates the figure could rise to 113 million barrels by 2030. The currently used energy resources will be unable to cope with future energy requirements since the fossil fuel reserves are already on a decline. Over the last few years the once-considerable gap between supply and demand has

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narrowed. Last year that gap all but disappeared. The consequences of a shortfall would be immense. One of the immediate impacts would be rocketing oil prices—within first 2 months of 2008, oil prices have twice crossed the psychological limit of $100 per barrel. It has been forecasted that if consumption begins to exceed production by even the smallest amount, the price of oil could soar above $100 a barrel which would result into a global recession [2].

The enormous amount of energy being consumed across the world is having adverse implications on the ecosystem of the planet. Fossil fuel and nuclear energy production and consumption are closely linked to environmental degradation that threatens human health and quality of life, and affects ecological balance and biological diversity. It is therefore clear that if the rapidly increasing global energy needs are to be met without irreparable environmental damage, there will have to be a worldwide drive to exploit energy systems that should not endanger the life of current and future generations and should not exceed the carrying capacity of ecosystems. Renewable energy sources that use indigenous resources have the potential to provide energy services with almost nil emissions of both air pollutants and greenhouse gases.

This work presents an overview of the current energy scenario for Pakistan in terms of its energy demand and supply, challenges and prospects. For secure and sustainable energy future, various renewable energy options have been explored. Hydropower and solar energy resources have been analyzed to determine their technical and economical viability.

2. Present energy scenario of Pakistan

Availability of energy in any country has a strong relationship with its economic and social stability. The per capita energy consumption is an index to measure the prosperity of any society. An overview of the energy scenario indicates that Pakistan is an energy deficient country. The per capita electricity consumption was 425 kWh in 2004–05. Over the same period, the world average per capita electricity consumption was about 2516 kWh, almost six times larger than that of Pakistan [3].

2.1. Energy resources and their contribution

The Pakistan's primary energy supply mix mainly consists of fossil fuels that contribute to more than 60% of the total supply. Biomass-based fuels in the form of fuel wood, agricultural and animal wastes contribute to almost 36% of the total supplies. In terms of commercial energy, the total consumption in 2005–06 was 74.4 MTOE corresponding to a per capita primary energy consumption of 0.49 TOE. The commercial energy shares, in 2005–06 were: gas, 50.3%; oil, 29.8%; hydro, 11.0%; coal, 7.6% and nuclear, 1.2%. So the primary energy use is mainly based on gas, oil and hydro while the use of coal and nuclear energy is very small. A breakdown of county's electricity supply indicates that thermal power plants have the biggest share, contributing to 64% (gas 35.5%, oil 28.5%, and coal 0.3%) of the total [4]. Hydropower and nuclear power contribute to 33% and 2.4% of the total electricity supply, respectively, as shown in Table 1. The domestic sector is the largest consumer of electricity accounting for 44.2% of total electricity consumption followed by industries 31.1% and agriculture 14.3% [5].

2.2. Energy demand and supply

Pakistan's energy demand far exceeds its indigenous supplies. Pakistan like other developing countries is energy deficient—the demand for primary energy in Pakistan has increased considerably over the last few decades and the country is facing serious energy shortage problems. The energy supply is not increasing by any means to cope with the rising energy demands. As a result the gap between the energy demand and supply is growing every year. The number of electricity consumers has increased due to rapid urbanization, extension of electricity grid supply to un-electrified areas and village electrification—the number of consumers has increased from 8.2 million in 1992–93 to 15 million in 2005–06 registering a growth of 83% over the last 15 years [6]. Estimates indicate that the energy demand in Pakistan is likely to increase three-fold by the year 2050. On the other hand, the situation with the supply end is not encouraging. The indigenous oil and gas reserves are limited—oil and gas reserves are left only for 19 and 10 years, respectively [7]. Abundantly available local coal reserves have not been capitalized to play a meaningful role in energy supply matrix of the country. The pace of new hydropower generation facilities has also slowed down over the last two decades for a number of reasons and nuclear power so far has managed to contribute to less than 3% of the total electricity supply mix.

Table 1
Historic electricity generation and capacity mix of Pakistan

Entity	Electricity generation capacity (MW)		Shares (%)	
	1980	2007	1980	2007
Coal	0.015	0.150	0.4	0.8
Oil	0.177	3.019	4.3	15.6
Gas	1.929	9.254	47.0	47.8
Hydro	1.847	6.494	45.0	33.5
Nuclear	0.137	0.462	3.3	2.4

With the advent of 2008 the country is facing an electricity deficit of over 4000 MW, a 40% of the total demand. In business as usual scenario by 2010 the deficit could reach over 8000 MW [8]. The balance of evidences thus suggest that the already existing gap between demand and supply is set to grow rapidly in the coming years unless quick and meaningful measures are taken to add to the power generation capacity of the country.

2.3. Rising energy cost

Increasing energy cost has been having an adverse impact on the economic conditions of the country at micro- and macro levels. The commercial energy- and electricity generation mix of the country heavily rely on fossil fuels the price of which, following the global trend, has risen sharply over the last few years as shown in Fig. 1. Soaring energy prices have become a serious concern for the vast majority of population in Pakistan. In 2007, for example, the price of petrol is nearly US$ 0.9 per liter. Considering per capita GDP of Pakistan, US$ 2600 [9], such a high price has increased the

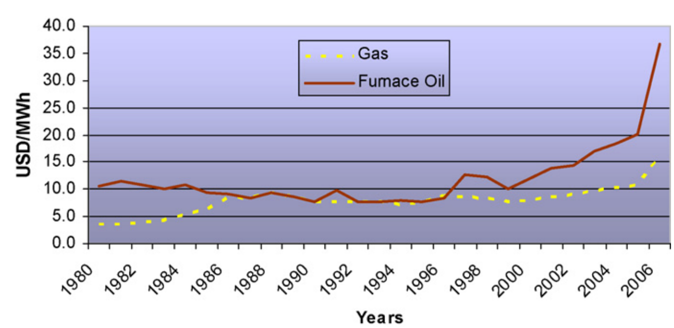


Fig. 1. Gas and furnace oil prices in Pakistan.

Table 2
Estimated installed and generation capacity of some of the identified projects

Project	Installed capacity (MW)	Generation capacity (GWh)
Bunji	5400	20,750
Bhasha	4500	
Dasu	4000	19,381
Kalabagh	3600	11,400
Thakot	2800	15,200
Patan	2800	
Kohala	1100	4,800
Neelum Jhelum	969	5,150
Munda	750	
Akhori	600	
Dubar Khwar	130	595
Allai Khwar	121	463
Golen Gol	106	436
Khan Khwar	72	306

levels of fuel poverty in the society. The rocketing fuel price has a direct knock on effect on all other living expenses making things unaffordable for a large proportion of population. The situation is decreasing the levels of sustainability in the society (Table 2).

3. Renewable energy in Pakistan

Renewable energy as the name implies is the energy obtained from natural sources such as solar, wind, solar energy, hydropower, biomass energy and geothermal energy. Renewable energy sources have also been important for humans since the beginning of civilization; biomass, for example, has been used for heating, cooking and steam production; wind has been used for moving ships; both hydropower and wind have been used for powering mills to grind grains. Renewable energy sources that use indigenous resources have the potential to provide energy services with zero or almost zero emissions of both air pollutants and greenhouse gases. Renewable energy resources are abundant in nature and are acknowledged to be vital and plentiful enough to meet many times the entire world's energy demand as shown in Fig. 2.

The prevailing electricity shortage in Pakistan is an indication of an unsustainable energy scenario for the country. It is therefore crucial for the country to adopt a diverse energy strategy which not only decreases dependence on vulnerable energy supply channels but one that also explores secure and sustainable energy resources such as renewables.

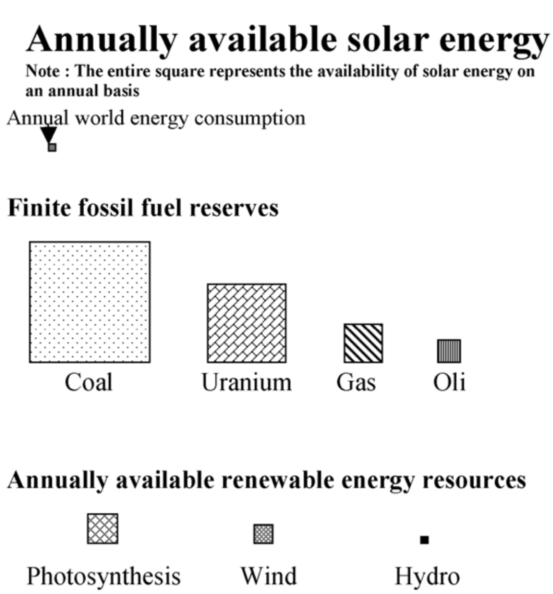


Fig. 2. Overview of global energy demands and available renewable energy potential.

Pakistan has proven potential for renewable energy, i.e. hydropower and solar energy. Exploitation of these resources can enhance diversity in Pakistani energy supply market, secure long-term sustainable energy supplies, cut down import dependency and also reduce atmospheric emissions. They can also provide commercially attractive options to meet specific needs for energy services (particularly in rural areas), create new employment opportunities, and offer possibilities for local manufacturing of equipment. The prospects of some of the crucial renewable energy technologies in Pakistan are discussed in the coming sections.

3.1. Hydropower

Hydropower can be regarded as a renewable form of energy; small and medium scale hydropower projects are considered to be perfect examples of renewable energy; the medium to large-scale projects for a time scale of few decades can also be regarded as renewable form of energy but over the longer time scale questions arise over their renewable identity as their capacity deflates due to silting. Hydropower is amongst the most mature and developed forms of renewable energy that presently holds a significant share in global energy market. A major contributor to world energy supplies, hydropower provides nearly 20% of world total electricity demands. There are many countries in the world where hydropower plays the predominant role in electricity supply mix. Norway, for example, produces 99% of its electricity from hydropower while Brazil produces 92% of its requirements from it. Similarly, Iceland produces 83%, Austria 67% and Canada produces over 70% of its electricity from hydropower. Presently, the largest hydropower system is Itaipu that is housed at Parana river between Brazil and Paraguay. With installed capacity of 12.6 GW, supported by 1350 km^2 of reservoir, and working at a load factor of up to 85%, it annually generates around 100 billion kWh of electricity [10].

Hydropower is one of the main sources of energy for Pakistan—as of 2007 hydropower contributes to nearly 33% of the total electricity supply mix. The country has enormous potential for the generation of hydropower. Estimates suggest the total identified potential is over 42 GW out of which only 15%, amounting to nearly 6.5 GW, has been exploited so far. The five major projects in this regard include Tarbela, Mangla, Warsak and Chashma and Ghazi Barotha, respectively, having a capacity of 3478, 1000, 240, 187 and 1450 MW [11]. A considerable part of the northern areas of Pakistan do not have access to grid mainly due to their remoteness and difficult terrestrial conditions. Most of these areas have a good degree of potential for small-scale facilities as nearly 300 micro and mini hydropower plants are already in operation. These hydropower plants are making valuable contribution to the lives of local inhabitants living in small villages and clusters of homes.

Despite these developments, the growth in hydropower generation capacity in the country has not been given the due attention as a result of which the contribution made by hydropower in total electricity generation mix has decreased from 70% in 1960 to 33% in 2006. The capacities of the existing three reservoirs based hydropower facilities in the country: Tarbela, Mangla and Chashma are declining due to sedimentation—the live storage capacity of the three reservoirs has been reportedly reduced by about 20% [11]. The growth in hydropower is disproportionate in comparison to that of the energy demand in the country. Over the last two decades the only meaningful hydropower activity has been the construction of 1450 MW Ghazi Barotha project.

Table 3
Electricity generation cost in 2006, by fuel type

Energy source	Cost/kWh	
	Pak Rs.	US cents
Hydro	0.3	0.5
Coal	1.3	2.1
Gas	2.4	4.1
Nuclear	2.7	4.5

The massive vacuum created by sluggish growth in hydropower has been filled by thermal power that now contributes to nearly 65% of the total electricity demands of the country. Here it is vital to understand that hydropower is an indigenous and renewable resource while oil (a key player in the thermal power generation) is by and large a foreign one since Pakistan meats nearly 80% of its oil demands through impacts [9]. This categorical shift from hydropower to fossil fuels thus implies that the country has seriously compromised on its energy security. In other words, Pakistan has become substantially dependent upon other countries to meet its energy requirements. In the wake of the ongoing geopolitical and military conflicts in the world, especially in and around this part of the world, the dependency upon foreign energy resources is not an ideal situation to be in. Another downside of the shift from hydropower to fossil fuels is the enormous fiscal burden. Reports suggest that over the last 3 years due to the steep rise in international oil prices the petroleum import bill has increased by more than 150%—from around $3 billion in 2004 to nearly 8 billion in 2007 [12]. In the last fiscal year it accounted for nearly a quarter of the total import bills of the country.

The declined share of hydropower in the energy supply mix of Pakistan is thus not a healthy sign in any respect. In order to surmount the prevailing energy crisis and to ensure a sustainable energy future multi-fold exploitation of hydropower is imperative. Pakistan must aim at switching the bulk of its electricity base back to hydropower as quickly as possible. Sufficient resource is there but what is missing is a combination of visionary policies and commitment. There are at least 7 potential hydropower projects in the country with capacity in multi-giggawatts (GW). These include Bhasha (4500 MW), Bunji (5400 MW), Dasu (4000 MW), Kalabagh (3600), Kohala (1100 MW), Patan (2800 MW) and Thakot (2800 MW). Apart from these, there are a number of other projects with capacity in hundreds of megawatts such as Neelam-Jhelum (950 MW), Munda (750 MW) and Akhori (600 MW) as given in Table 3. Furthermore, Water and Power Development Authority of Pakistan (WAPDA) has also identified a number of other projects worth collective capacity of more than 2400 MW as shown in Fig. 3 [8,13]. Notwithstanding initial work in the form of feasibility or pre-feasibility reports was undertaken on almost all of these potential projects years (and in some cases decades) ago, construction of any of these is yet to be initiated. Apart from these large-scale reservoir projects there are also a large number of potential medium to small-scale and run-of-river projects.

Hydropower by far is the most economical source of electricity in Pakistan. On average, the electricity production through hydropower during 2006–07 accounted for a cost of US scents 0.5 kWh^{-1} which is the most economical choice as shown in Table 3 [14]. The economics of the aforementioned identified projects suggest a payback period of 3–4.5 years [8].

3.2. Solar energy

Solar energy is one of the most promising renewables. It is very consistent and is not significantly vulnerable to changes in seasonal weather patterns. It can produce power at the point of demand in both rural and urban areas. Solar energy can be exploited through the solar thermal and solar photovoltaic (PV) routes for various applications. While solar thermal technologies utilize the heat energy from the sun for various purposes, solar photovoltaic technology enables direct conversion of sunlight into electricity through semi-conductor devices called solar cells.

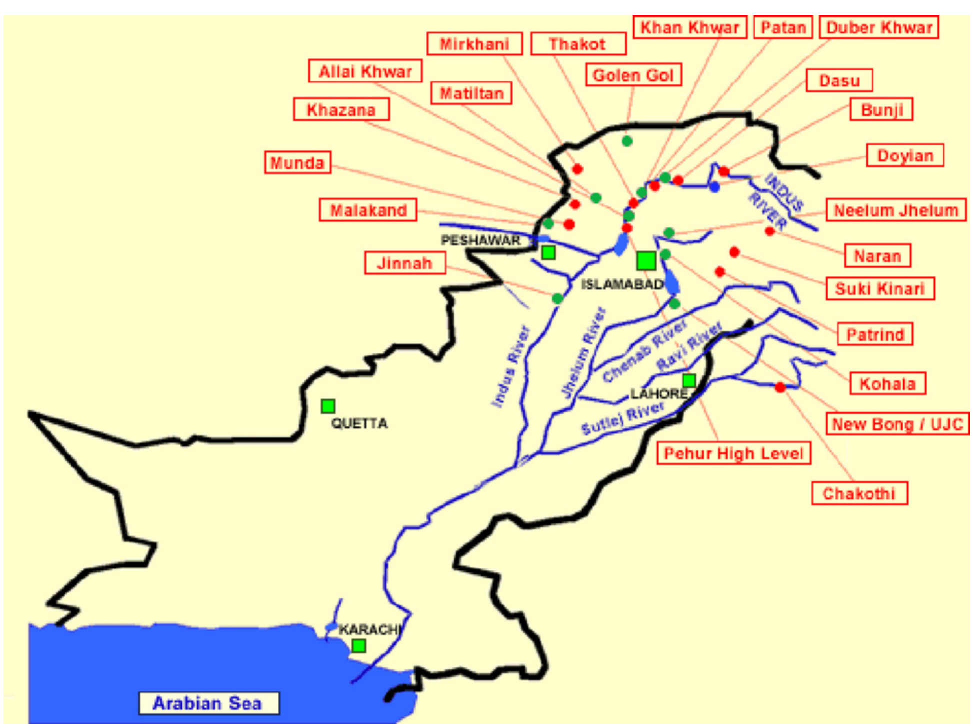


Fig. 3. Identified sites for hydropower generation.

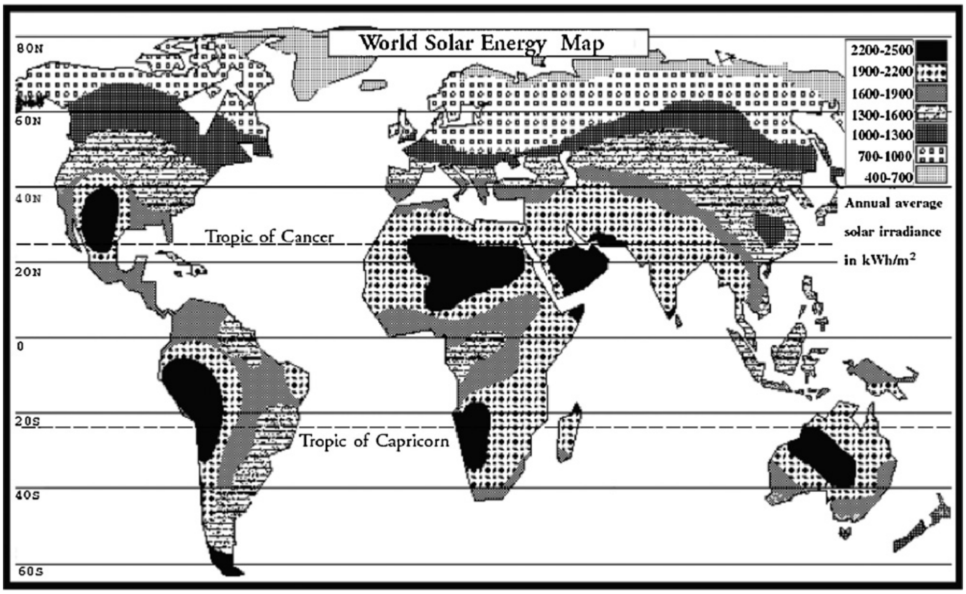


Fig. 4. Global solar radiation map of the world.

The geographic location, topography and climate conditions of Pakistan make it an ideal candidate for exploiting solar energy. On average, almost all parts of the country have more than 300 sunshine days in a year. The availability of 1900–2200 kWh/m^2 of annual global irradiance [15], as shown in Fig. 4, ranks Pakistan amongst the richest countries of the world in terms of solar energy potential. The figure also indicates that the distribution of solar radiation is fairly consistent throughout the country. The available solar radiation make the climatic conditions of Pakistan highly favorable for solar energy applications such as solar photovoltaic, solar water heating, solar desalination and solar crop drying.

Solar photovoltaic can be a very useful technology to deliver electricity in remote applications where grid connectivity is impractical. For example, in far-off villages of Balochistan, Cholistan and Thar deserts, solar photovoltaic can be a more convenient and value engineered solution to provide electricity for basic needs.

Solar water heating, one of the oldest and the most successful applications of solar thermal technologies, utilizes solar energy to heat water without producing harmful emissions into environment. It is also one of the fastest growing renewable technologies in the world [16]. Solar water heating, besides its domestic role, has a wide array of applications within commercial (such as swimming pools, laundries, hotels and restaurants) and industrial sectors (such as food and beverages, process, and textile industries). Around the world, water heating accounts for as much as 15–25% of the total energy consumed in domestic sector. In the USA and UK, for example, water heating, respectively, consumes 18% and 23% of the domestic energy [17]. While in the industrial sector, water heating may account for a significantly higher share of energy. In the textile sector water heating can account for as much as 65% of the total energy used during process such as dyeing, finishing, drying and curing [18]. Solar water heating is a prospective technology for countries like Pakistan that can deliver clean energy with economy. It has been reported that nearly 10% of the total primary energy in Pakistan is consumed in water heating. Solar water heating under Pakistan's climatic condition can have a pay back period of less than 3 years [16]. Solar water heating thus can make a significant contribution to the energy supply mix of the country and help reduce the national reliance on energy imports.

3.3. Biomass

Biomass plays an important role in the primary energy mix of Pakistan. The country's large agricultural and livestock sector produces copious amounts of biomass in the form of crop residues and animal waste, such as bagasse, rice husk, and dung, much of which is currently collected and used outside the commercial economy as unprocessed fuel for cooking and household heating. These biomass-based fuels, in conjunction with wood contribute to almost 36% of the total primary energy mix. Sugar mills in the country use bagasse for cogeneration purposes and have recently been allowed to sell surplus power to the grid up to a combined limit of 700 MW [19]. Apart from this, biomass-based fuels have not managed to break into the commercial market. In past, pilot projects of biogas digesters have been launched. The use of biogas digesters in rural households, after a promising start, has stagnated due to withdrawal of external subsidies. In addition, municipal solid waste produced by a large urban population is presently openly dumped, which could instead be disposed of in proper landfills or incinerated to produce useable methane gas or electricity.

Pakistan holds a healthy potential for biofeuls that can help country partly meet its oil requirements, 80% of which are presently being met through imports [20]. Recently, initiatives have been undertaken to promote biofuels, as part of which, in 2006, in three petrol stations (one in Karachi, Lahore and Islamabad each), fuel ethanol is being blended with petrol in a 1:9 ratio [21]. Pakistan Sugar Mills Association (PSMA) has been closely involved in the biethanol advancement program. As of 2007, out of more than 70 sugar mills in the country only 6 have facilities to transform raw molasses into fuel quality ethanol. With the current production level of sugarcane crop, Pakistan has a potential to produce over 4,00,000 tones of ethanol. Nonetheless, less than one third of it is being currently produced [22]. Most of the pilot projects launched so far being of cosmetic value the wider perception is that despite the potential advantages, progress in promoting bioethanol lacks policy impetus. State of affairs is that most of the bioethanol base is being exported in different forms, i.e. molasses, industrial alcohol and ethanol. There is also a considerable potential for bodiesel production. One of the prospective sources in this regard is castor bean. It is a self-gown plant seen in

Table 4
Comparison of potential energy crops for biodiesel production

Crop	kg oil/ha
Castor beans	1188
Corn (maize)	145
Mustard seed	481
Rapeseed	1000
Sesame	585
Soybean	375
Sunflowers	800

many parts of Pakistan particularly in arid and semi-arid areas. Here it is noteworthy that castor bean has the highest oil content amongst oil crops grown in Pakistan as shown in Table 4 [23]. Castor oil (derivative of castor been) is regarded as one of the best substances to produce biodiesl because it is soluble in alcohol and does not require heat and consequent energy requirement as other vegetable oils do in transforming them into biodiesel. Detailed figures and mappings for castor been production in Pakistan are not available. Castor oil is very much an untapped resource in Pakistan. With a little attention it can be converted into a healthy biodiesel resource for the country. With petroleum import bill in fiscal year 2006–07 reaching around $8 billion, substituting petrol and diesel, respectively, with biethanol and biodiesel could generate substantil foreign exchange savings [24].

3.4. Wind power

Wind power is one of the fastest growing renewable technologies in the world. Within the recent past, the annual market for wind has continued to increase at the staggering rate of over 25% following the 2005 record year in which the market grew by 41%. Over 20 GW of wind power was installed in 2007, led by the US, China and Spain, bringing worldwide installed capacity to 94.12 GW. The top five countries in terms of installed capacity are Germany (22.3 GW), the US (16.8 GW), Spain (15.1 GW), India (8 GW) and China (6.1 GW) [25,26].

It is reported that commercially exploitable wind resources exist in southern parts of Pakistan, especially in coastal areas of Sindh and Balochistan provinces, with monthly average wind speeds reaching 7–8 m/s at some sites along the Keti Bandar-Gharo corridor [19]. Fig. 5 provides the wind map of Pakistan at a height of 50 m [27]. The country, however, has not yet been able to exploit its wind energy potential—as of early 2008, no commercial wind farms are in operation, though some small-scale wind turbines have long been pilot tested for community use. The very first efforts to identify possible exploitation of wind energy for water pumping and aero-generation in Pakistan were made in 1980s [28]. In the year 2002, 14 small wind turbines, six of 500 W each and eight of 300 W each, were installed for demonstration purpose. Out of these, eight were installed in the coastal belt of Balochistan and six in the coastal areas of Sindh. That demonstration project has been concluded successfully—these small wind turbines have been found to be both technically and economically viable for electrification of the remote communities [29]. With the help of the detailed data made available over the last 5 years, it is now possible to develop a clearer picture of the wind potential in the country. There are plans to produce 700 MW of wind power in Gharo (Sindh). The aim is to inject this power within the national grid by 2010 [27]. Longer term aims are to develop 9.7 GW of wind power by 2030 [30].

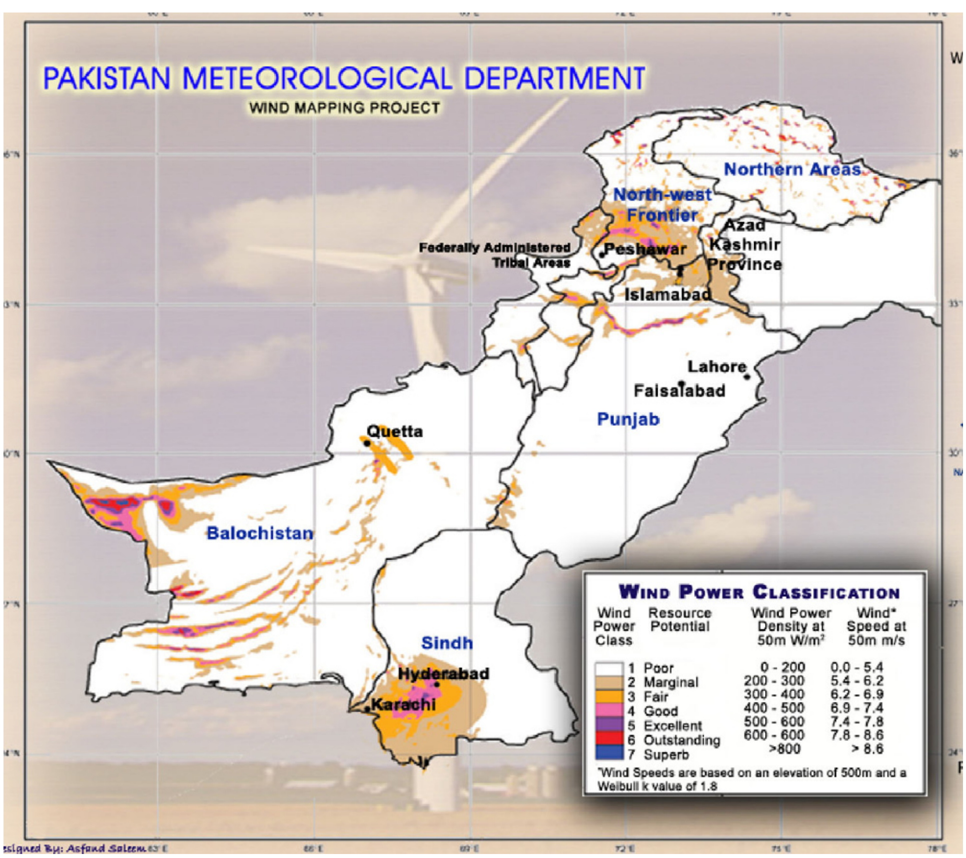


Fig. 5. Wind energy map of Pakistan at a height of 50 m.

4. Conclusions

In order to ensure a sustainable energy future, Pakistan needs to diversify its supply mix. Exploitation of indigenous energy resources should be at the heart of the future strategies to enhance energy security of the country through lessening reliance on energy imports. Renewable energy has a crucial role to play in Pakistan's sustainable energy future. Hydropower is technically and economically the most mature form of renewable energy. Of the available 42 GW potential, only 15% have been exploited so far. Hydropower is closely linked with the economic prosperity of the country and has a leading role to play in future energy scenario of Pakistan. Besides large-scale hydropower generation facilities, small to medium scale ones are also critical to be developed to contribute to the national electricity supply mix. The economics of hydropower considerably depends upon the typical site. Analysis suggests that almost 90% of the hydropower facilities in Pakistan incur a payback period of 2.5–4 years.

Another important form of renewable energy that is abundantly available in Pakistan is solar energy—figures show that the annual incident solar radiation in the country is 1900–2200 kWh/m^2. Such a high level of available solar energy can be effectively capitalized both for solar electric and solar thermal applications. Solar water heating, one of the fastest growing renewable technologies in the world, exhibits a healthy potential in Pakistan with a reported pay back period of less than 3 years.

Biomass in the form of crop residues and animal waste plays an important role in the primary energy mix by contributing to 36% of the total supplies. It, however, has not managed to break into the commercial energy market. There is a significant potential for commercial exploitation of municipal solid waste and biofuels. In terms of wind power, the country has not yet been able to exploit its resource. There are, however, plans to produce 700 MW of wind power by 2010.

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